Water Column Variability in Coastal Regions

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LONG-TERM GOALS

The long-term goal of this research is to obtain a quantitative understanding of the processes that cause variability in coastal waters over time scales of hours, days, weeks, and longer. The important processes on these short to moderate term time scales are mainly physical, chemical, and biological. Variations in a number of water column properties can be driven by either internal processes such as biological activity, chemical reactions, and mixing of waters or by external forcing from the atmosphere, from runoff and inputs from land, or from exchanges with offshore waters of energy, mass, and biota.

OBJECTIVES

Our objective is to determine the processes that cause water column variations in coastal regions with sufficient detail to provide a basis for predicting these changes in coastal water properties. Our primary focus is on oxygen, carbon dioxide, suspended particulate matter, chlorophyll, temperature, and salinity. These properties were selected because their variations reflect a wide range of processes including (i) *in situ* photosynthesis, respiration, and decomposition of organic matter, (ii) air-sea gas exchange, (iii) response to meteorological conditions (solar radiation, wind velocity, and heat fluxes), (iv) tidal mixing, stratification, water mass variations, (v) runoff from land, and (vi) anthropogenic inputs.

APPROACH

The approach taken in this work has consisted of combining satellite remote sensing with water column measurements using *in situ* sensor instruments. We have used AVHRR remote sensing to determine sea surface temperature variations in coastal waters and to detect variations in suspended particulate matter. We are examining the use of SeaWiFS remote sensing to relate surface chlorophyll and optical properties to the results obtained from *in situ* sensor measurements and AVHRR images. The *in situ* measurements have consisted of time-series observations at fixed sites, underway measurements of near-surface properties, and profiling of vertical gradients.

WORK COMPLETED

Ms. Wendy Woods is nearing completion of her doctoral studies which are examining water column measurements and satellite remote sensing (AVHRR and SeaWiFS) in the coastal waters of China. Kester has been working with and assisting Dr. Danling Tang who completed a Ph.D. degree at Hong

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Kong University of Science and Technology in 1998 in a study of ocean color and SST remote sensing in the coastal waters of China and the South China Sea. Prof. Cynthia Zoski, an electrochemist in the URI Chemistry Department, has worked with us on the use of *in situ* time-series sensors, and she is conducting research on new types of microelectrodes for marine environmental applications.

A paper by Magnuson and Kester has been reviewed and is under revision for Journal of Geophysical Research–Oceans which presents results of continuous underway measurements in Gulf Stream-Slope-Shelf waters off the northeast U.S. coast. A suite of surface water properties including temperature, salinity, oxygen, pH, and chlorophyll were used to detect distinctive water masses, fronts, and sites of chemical and biological activity. Using an alkalinity-salinity relationship based on discrete water samples and the continuous underway pH measurements, we calculated the partial pressure of CO_2 (pCO_2) and the total dissolved inorganic carbon (DIC) concentration in surface waters along transects from the Gulf Stream to the coast. Analyses of the O_2-DIC and the O_2-pCO_2 variations across fronts, and in several waters masses were used to identify the relative importance of air-sea gas exchange and biological activity in these offshore waters. Two papers are being submitted to Limnology and Oceanography on the annual cycle of waters near the entrance of Narragansett Bay based on an uninterrupted time-series of measurements (T, S, O_2, pH, water level) every ten minutes for one year. One paper presents the methods, data set, and general results; the other paper examines the processes revealed using time-series analysis methods. This study documents the roles of warming and cooling, of winds and storms, of neap and spring tides, and of variations in solar radiation on the physics, chemistry, and biology of a coastal system. We have seen the times of the year when phytoplankton blooms are most frequent, and when they are absent. These bloom events are often of short duration (3-5 days), and without the continuous observations that are possible with automated sensors, many blooms would not be detected by more traditional weekly, biweekly, or monthly measurements.

Fox, Kester, Andrews, Magnuson, and Zoski have prepared a paper for Journal of Geophysical Research that examines the seasonal warming of lower Narragansett Bay and Rhode Island Sound during 1997. This paper combines AVHRR SST observations, our multi-depth moored buoy data, the GSO-dock time-series data, and measurements from a NOAA offshore weather buoy to show the relationship between water properties in a bay and in offshore waters during winter, spring, and summer. The AVHRR SST images were used to detect and characterize the front between waters of the Bay and those of the Sound. Figure 1 illustrates the type of SST variations seen in this region. The surface waters in the Bay warm slightly faster than the bottom waters producing an increasingly stratified water column. We found a very close relationship between the bottom water warming rate in the Bay and the surface water warming rate in RI Sound using AVHRR and NOAA buoy surface measurements. We concluded that the *bottom* waters in the Bay acquire their properties at the *surface* in the Sound, and they are then transported into the Bay beneath the Bay's less dense surface layer.

Tang, Ni, Kester, and Müller-Karger have conducted a study of a winter phytoplankton bloom phenomenon first discovered by Kester and Fox (1993) in the South China Sea (SCS) southwest of the Luzon Strait using CZCS ocean color data. Based on satellite data from 1978-1986 and historical hydrographic station data in the SCS we conclude that during the winter monsoon of most, if not all years, there is an upwelling process southwest of the Luzon Strait that brings nutrients into the euphotic zone and increases phytoplankton biomass. This paper is in press in Marine Ecology Progress Series.

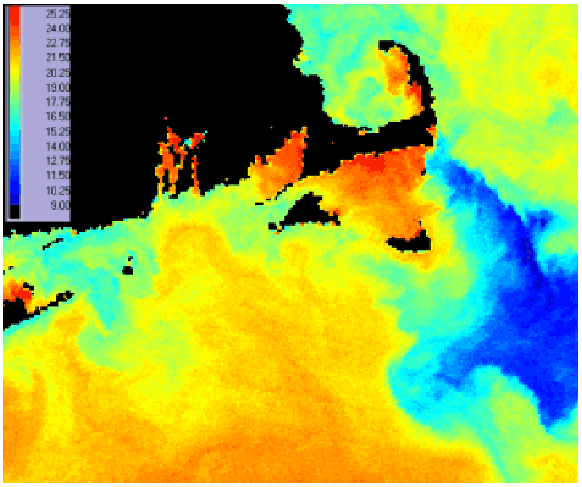

Figure 1. SST image on 8 July 1999 of waters from the entrance of Long Island Sound, south of Narragansett Bay, and around Cape Cod.

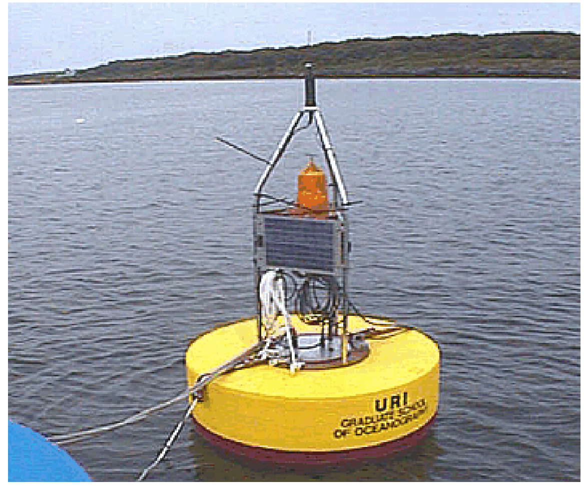

Figure 2. Buoy for water column measurements. Sensors for T, S, O_2, pH, chlorophyll are located 0.5 m below surface and 1 m above the bottom.

Tang, Ni, Müller-Karger, and Kester also wrote a paper using the CZCS data set on the monthly variations of phytoplankton pigments along the coast of China from the Bo Hai to Viet Nam. This study provides the first systematic analysis of the spatial and seasonal pattern in surface water biomass for that region. Regions of particularly high pigment concentrations during the spring and summer months include the Bo Hai, Yellow Sea, and Taiwan Strait. The influence of the Yangtze River plume in creating a region of high pigment concentration was also evident in this analysis.

In the studies of coastal processes in the region of Hong Kong we examined the influence of the Pearl River discharge on the waters around Hong Kong during the wet and dry seasons. We determined the influence of the winter and summer monsoons on these waters. We determined the annual cycle of physical and chemical conditions in Port Shelter Bay (in the east portion of the Hong Kong territory). We made several observations on the physical and chemical conditions associated with harmful algal blooms in Hong Kong waters. The methods we used in this work included (1) a water column time-series measurement system in Port Shelter Bay off the campus of HKUST; (2) the use of satellite remote sensing (AVHRR and SeaWiFS) in the coastal waters of China; (3) a series of 21 cruises in Hong Kong waters and across the Pearl River estuary to Macau; (4) use of an underway marine environmental mapping system that integrated measurements of surface water properties (T, S, O_2, pH, turbidity, and chlorophyll fluorescence) with a GPS electronic charting system. Ms. Woods collected and analyzed samples for suspended particulate matter, chlorophyll, and colored dissolved organic matter to use with satellite remote sensing analysis. The field work for these studies was completed in November 1998 and January 1999 when we obtained measurements near the beginning and the middle of the winter monsoon for comparison with our field studies during the 1998 summer monsoon.

In June 1999 Kester and Woods presented papers at the International Workshop on Marine Environmental Measurements held in Hong Kong. A series of papers are being prepared based on the work done in Hong Kong. One paper will address the annual cycle of waters in Port Shelter Bay with emphasis on how they are influenced by the winter/summer monsoon cycle. Another paper will present the effects of the waters from the Pearl River estuary on the region of Hong Kong. There will be several

papers based on satellite remote sensing in the Hong Kong region which will link together the *in situ* measurements and remote to show the spatial and temporal variations in surface properties. During 1999 Tang and Kester are working with colleagues at the South China Sea Institute of Oceanology on a paper that examines the thermal plume from the Daya Bay nuclear power plant.

In March 1999 Kester presented an invited paper at the NE Section Meeting of the Geological Society of America on the time-series studies in RI waters. This paper showed the importance of stratification in the water column as a condition for high rates of phytoplankton photosynthesis.

In June 1999 we deployed two new moored buoys for time-series measurements in Narragansett Bay (Figure 2). One buoy is located in the upper Bay where it detects responses to the system from fresh water inputs and urban nutrient inputs. The second buoy is located in the mid-region of the Bay between Quonset Point and Newport. Both buoys are equipped with sensors at a depth of 0.5 m below the surface and 1.0 m above the bottom which is about 12-14 m deep. When the Bay is stratified the pycnocline is usually at about 2-3 m depth. Sensors at both depths measure temperature, salinity, oxygen, pH, and hydrostatic pressure (from which tidal and water level variations can be determined). The surface sensors also include chlorophyll fluorescence. Measurements are obtained every 15 minutes. The buoys are self-contained with solar panels that re-charge the batteries onboard, and with a cellular telephone modem that is used to transfer the data ashore and to monitor the instrument performance. The sensors are serviced at 2-3 week intervals to remove biofouling and to provide sensor re-calibration.

RESULTS

The buoy data over the past few months have shown a number of new things about processes in the Bay and the exchange of waters between the Bay and offshore areas that were previously unknown. While a number of biological studies (mainly in oceanic waters) emphasize that light inhibition may be important in surface waters, we find that in these coastal waters photosynthetic oxygen production and increases in chlorophyll biomass occur mainly when there is a series of bright sunny days–even in the upper 0.5 m of the water column. A cloudy day will diminish greatly the daily oxygen production, and a series of cloudy days can terminate a phytoplankton bloom. Primary production in these waters is very sensitive to the amount of sunlight available. Phytoplankton blooms in the Bay occur almost always during quarter phases of the moon, and not during the new moon phases when tidal amplitudes are greatest. We believe this observation is related to the important role of stratification in supporting a phytoplankton bloom. When the water column (with depths ranging from 10-15 m) are vertically mixed the phytoplankton are unable to achieve high photosynthetic rates. For some species this could be due to the effects of turbulence, and for others it may be due to low levels of light when averaged over the mixing water column.

Several general conclusions can be derived from our work. Biological primary production and phytoplankton blooms vary with the amount of sunshine and cloud cover in both RI and Hong Kong. Water column stratification varies with the phase of the moon due to differences in neap and spring tidal amplitudes. Bloom events are relatively short in duration–3 to 5 days–requiring frequent measurements to be adequately resolved. We see the effects of runoff from major storm events in Narragansett Bay, such as the unusually rainy period in the early summer of 1998. We also see the dramatic influence of the summer monsoon in the area of Hong Kong when the increased Pearl River discharge reduced the upper water salinities and increased their turbidity and nutrient levels by large

amounts. Our findings are similar to those in the western Baltic Sea by Fennel (1999) in showing the importance of stratification on phytoplankton blooms.

IMPACT/APPLICATIONS

The results of this work will be highly portable to other coastal locations. The instrument packages, the integration of *in situ* and satellite data, and the formulation of a forecasting capability can be applied readily to other sites. It should be possible to make an initial assessment of the sensitivity of a new area to the basic forcing functions using satellite remote sensing. This assessment can be enhanced by a limited term deployment of *in situ* measurement systems.

During the summer of 1999 we used our time-series observations along with our previous analyses of processes in RI coastal waters to provide predictions of the likelihood of phytoplankton blooms. These predictions were distributed to about 25 of our colleagues who are working in this area so they could use the information in their sampling and studies. By focusing this work on achieving a coastal water column forecasting capability, we have not only a useful product for practical applications, but we have a severe test of our understanding of the underlying processes. Following the work of Simpson and co-workers we should be able to quantify these forecasts in the future (Simpson *et al.*, 1990; Czitrom and Simpson, 1998; Simpson, 1998).

TRANSITIONS

During this past year a group of investigators engaged in physical, chemical, and biological studies in Narragansett Bay have coordinated their efforts to provide a more comprehensive view of events and ecosystem responses. We are distributing “State of the Bay” assessments once or twice a week to 25 investigators who are affiliated with the University of Rhode Island, Brown University, the Naval Underwater Warfare Center – Newport, RI, the U.S. Coast Guard R&D Center -- Groton, CT, the NOAA National Marine Fisheries Service – Narragansett Laboratory, and the EPA Narragansett Laboratory. Our time-series data are providing a context in which other investigators can better plan and understand their studies of these coastal waters.

RELATED PROJECTS

Our ONR-funded research has been designed for applicability to a wide range of coastal environments and we have pursued this work in Rhode Island and Hong Kong coastal waters. Information gained from the time-series measurements has prompted considerable interest. We are working with several investigators to establish an observing system in RI waters with an initial focus on Narragansett Bay. NOAA has funded the purchase of two automated buoy systems that were deployed in the upper and middle portions of the Bay. These systems along with our time-series measurements near the mouth of the Bay allow us to determine the progression of phytoplankton blooms, the effects of freshwater input events, and the intrusions of offshore waters as they progress through the Bay. We have been informed that an EPA EMPACT project of which we are a partner will be funded, and it will provide for the installation of two additional time-series measurements systems near the head of Narragansett Bay in the urban area of Providence, RI.

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